Faculty of Mechanical Engineering

MECHANICAL PERFORMANCE OF PINEAPPLE LEAF FIBRE REINFORCED POLYLACTIC ACID BIOCOMPOSITES

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Master of Science in Mechanical Engineering

2018

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

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DECLARATION

I declare that this thesis entitled "Mechanical Performance of Pineapple Leaf Fibre Reinforced Polylactic Acid Biocomposites" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:……………...
Supervisor Name	:………………………..................................
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DEDICATION

To my beloved family

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ABSTRACT

To-date, there is a large body of knowledge in the literature on the development of biocomposites. Nonetheless, some of the main limitation is the brittleness of the biocomposites when using PLA matrix which lead to relatively poor mechanical performance of the biocomposites. Thus, the main objectives of this research project are (i) to evaluate the effect of alkaline pre-treatment and fibre length on PALF reinforced biocomposites; (ii) to determine the effect of varying PLA matrix on the mechanical properties of the biocomposites and (iii) to study the effect of strain rate on the impact response of PALF reinforced PLA biocomposites (quasi-static vs. dynamic loading). The pineapple leaf fibre was pre-treated using sodium hydroxide (NaOH) prior to fabrication. The biocomposite with fibre loading of 30 wt.%. were fabricated either using two-step compression moulding (long fibre biocomposites) or melt-mixing and compression moulding (short fibre biocomposites) with fibre length of approximately 30 mm and 150 mm respectively. Following these, the biocomposites were characterized in terms of their flexural properties as a function of fibre length, surface modification and use of different grades of the PLA matrix, in accordance with ASTM D 790. Sodium hydroxide was found to augment mechanical performance by promoting enhanced adhesion at the fibre/matrix interface. Alkaline-treated biocomposites exhibit much greater flexural strength and modulus in comparison to those of the untreated samples, an indication of an improved interfacial bonding between the fibre and the matrix, as evident in the SEM micrographs, with rough surface on the alkaline-treated PALF. Moreover, the flexural properties of the biocomposites exhibit superior performance when fabricated using long PALF (150 mm) rather than the short PALF (30 mm), suggesting an efficient load transfer capability. In addition, the biocomposite samples based on PLA 6100D grade exhibit superior flexural and tensile properties, relative to those of the 3251D based biocomposites, due to its ductile nature. In addition, thermal analysis of the PLA matrices showed that different degree of crystallinity is observed for both types of matrices. Lastly, in terms of strain rate effect, results following quasi-static and dynamic loading on the long PALF reinforced biocomposites show that higher magnitude of the maximum force and greater amount of damage are present in the biocomposites when subjected to the dynamic loading. In addition, the PLA 6100D based biocomposites exhibit significantly much better performance in flexural, tensile and impact tests compared to 3251D based biocomposites. These findings suggest that fibre length, matrix material, surface modification and strain rate have an effect on the mechanical performance of the pineapple leaf fibre reinforced biocomposites.

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ABSTRAK

Sehingga kini, terdapat banyak pengetahuan dalam kajian ilmiah mengenai perkembangan biokomposit. Walau bagaimanapun, beberapa kelemahan utama adalah kerapuhan biokomposit apabila menggunakan matrik PLA yang membawa kepada prestasi mekanikal yang lemah bagi bahan biokomposit. Justeru, objektif utama projek penyelidikan ini (i) untuk mengkaji kesan rawatan alkali dan panjang gentian daun nanas ke atas sifat mekanikal bahan biokomposit; (ii) untuk memahami kesan penggunaan bahan matriks polimer ke atas sifat mekanikal bahan biokomposit dan (iii) mengkaji kesan kadar beban yang dikenakan (kuasi-statik berbanding beban dinamik) ke atas sifat hentaman bahan biokomposit PLA diperkuat gentian daun nanas. Gentian daun nanas telah dirawat menggunakan natrium hidroksida (NaOH) sebelum fabrikasi. Biokomposit dengan pecahan berat gentian sebanyak 30 wt%. telah dihasilkan sama ada menggunakan acuan mampatan dua langkah (biokomposit gentian panjang) atau melt-mixing dan pencampuran (biokomposit gentian pendek) dengan panjang gentian masing-masing sekitar 30 mm dan 150 mm. Seterusnya, biokomposit dicirikan dari segi sifat lenturannya sebagai fungsi panjang gentian, pengubahsuaian permukaan dan penggunaan gred matriks PLA yang berbeza, mengikut ASTM D 790. Natrium hidroksida didapati meningkatkan prestasi mekanikal dengan peningkatan lekatan pada antara gentian dan matriks. Biokomposit yang dirawat dengan alkali memperlihatkan kekuatan lenturan dan modulus yang lebih tinggi berbanding dengan sampel yang tidak dirawat, menunjukkan antaramuka yang lebih baik antara gentian dan matriks, seperti yang ditunjukkan di dalam mikrograf SEM, dengan permukaan kasar pada PALF yang dirawat alkali. Selain itu, ciri-ciri lentur biokomposit menunjukkan prestasi yang unggul apabila diperkuat PALF yang panjang (150 mm) berbanding PALF yang pendek (30 mm), menunjukkan keupayaan pemindahan beban yang berkesan. Selain itu, sampel biokomposit berasaskan bahan polimer matriks 6100D mempamerkan sifat lentur dan tegangan yang unggul, berbanding dengan biokomposit yang berasaskan bahan matriks PLA 3251D, kerana sifat mulurnya. Di samping itu, analisis haba matriks PLA menunjukkan bahawa terdapat tahap penghabluran yang berbeza bagi kedua-dua jenis matriks. Akhir sekali, dari segi kadar beban yang dikenakan, keputusan yang diperolehi daripada ujian beban kuasi statik dan dinamik pada biokomposit yang diperkuat oleh PALF panjang menunjukkan bahawa magnitud yang lebih besar dari segi beban maksima dan jumlah kerosakan yang lebih besar hadir dalam biokomposit apabila dikenakan beban dinamik. Di samping itu, biokomposit berasaskan PLA 6100D menunjukkan prestasi yang jauh lebih baik dalam ujian lenturan, tegangan dan hentaman berbanding dengan biokomposit yang berasaskan 3251D. Penemuan ini mencadangkan bahawa panjang gentian, bahan matriks, rawatan permukaan dan kadar beban dikenakan mempunyai kesan terhadap prestasi mekanikal biokomposit yang diperkuat gentian daun nanas.

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ACKNOWLEDGEMENTS

All praise to be Allah, the Most Beneficent, the Most Merciful. We bear witness there is no god but Allah and Muhammad is the Messenger of Allah.

This thesis represents my work about three years in Universiti Teknikal Malaysia Melaka (UTeM) and specifically within the Composite Laboratory.

First and foremost, I wish to express my appreciation and indebtedness to my dear supervisor Dr. Siti Hajar binti Sheikh Md Fadzullah for her precious guidance, encouragement, moral support and ideas to improvement throughout my MSc research. I am also grateful to Dr. Zaleha binti Mustafa as my second supervisor from Faculty Manufacturing Engineering who took keen concern in the work as well as her guidance in forming my ideas into brilliant ideas and for valuable discussion.

Also, gratefulness to the financial funding of to the Ministry of Higher Education (MOHE), Malaysia Ministry of Science, Technology and Innovation for sponsoring this work under RAGS/1/2014/TK04/FKM/02/B00069 research grant and scholarship from MyBrain15 through the duration of my study. Special thanks to Advanced Material Research Group (A-MAT), Faculty of Mechanical Engineering (FKM) and Faculty Manufacturing Engineering (FKP) of University Teknikal Malaysia Melaka (UTeM) for the use of facilities of laboratories during this research project. Additionally, I praise the enormous amount of help and teaching from staff of Chemistry Laboratory, Composites Laboratory, Polymer Laboratory and Science Laboratory for conducting on SEM during my experimental work. Thanks you to those who helped with the project and supported me in many ways: Hidayah Omar, Faizah Che Long, Nurlaela Said, Zailinda, Atiqah Lazim, Hajar Adni, Or Kai Hee, Hafizah Kassim,and Mashitah Razi.

Special thanks to mother, sisters, brothers and peers for their moral support and love. I would have never succeeded this if I did not get the moral encouragement from them. Lastly, thanks you to everyone who had been a part of realization of this project.

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LIST OF ABBREVATIONS

PALF	Pineapple Leaf Fibres
PLA	Polylactic acid
FRP	Fibre Reinforced Polymers
PMC	Polymer Matrix Composites
MMC	Metal Matrix Composites
CMC	Ceramic Matrix Composites
NFC	Natural Fibre Composites
NaOH	Sodium Hydroxide
OH	Hydroxyl Groups
TPS	Thermoplastic starch
FTIR	Fourier Transform Infrared Spectroscopy
DSC	Differential Scanning Calorimetry
SEM	Scanning Electron Microscope
ESEM	Environmental Scanning Electron Microscope
TMA	Thermo Mechanical Analysis
TGA	Thermal Gravimetric Analysis
DMA	Dynamic Mechanical Analysis
LDPE	Low-Density Polyethelyne
HDPE	High-Density Polyethelyne
PP	Polypropylene
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PVC	Polyvinyl Chloride
PS	Polystyrene
PBAT	Polybutylene Adipate Terephthalate

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PCL	Polycaprolactone
PHA	Polyhydroxyalkanoates
PHB	Polyhydroxybutyrate
PLLA	Poly (L-Lactic Acid)
PDLA	Poly (D-Lactic Acid)
ABS	Acrylonitrile-Butadiene-Styrene
EPDM	Ethylene Propylene Diene Copolymer
DOT	Department of Transportation
CO_2	Carbon dioxide
ASTM	American Society for Testing and Materials
LUT	Long Untreated Fibre
LT	Long Treated Fibres
SHUT	Short Untreated Fibres
SHT	Short Treated Fibres
PALFNA	PALF fibre treated with alkaline
PALFSI	PALF fibre treated with silane
PALFNASI	PALF fibre treated with alkaline and then silane agent
UTM	Universal Testing Machine
NW	Non-woven
W	woven

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LIST OF SYMBOLS

F	Force
A	Area
R	rate of cross head motion, mm/min
Z	rate of straining of the outer fibre mm/mm/min = 0.01
L	support span, mm
b	width of specimen, mm
d	depth of specimen, mm
T_c	crystallization temperature
T_g	glass transition temperature
T_m	melting temperature
σ_f	maximum flexural stress, MPa
E_f	modulus of elastic in bending, MPa
m	Slope of the tangent
m	mass
v	Velocity
X_c	degree of crystallinity
ΔHm	Experimental melting enthalpy (J/g)
$\Delta H^0 m$	Melting enthalpy of pure crystalline matrix
V_f	Fibre volume fraction
V_m	Matrix volume fraction
υ_f	Volume of fibre
υ_m	Volume of matrix
υ_c	Volume of the composite
W_f	Fibre volume fraction
W_m	Matrix weight fraction

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ω_f	Weight of fibre
ω_m	Weight of matrix
ω_c	Weight of the composite
g	gram

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LIST OF PUBLICATIONS

JOURNAL PAPER

1. **Ramli, S. N.R.,** Fadzullah, S.H. and Mustafa, Z., The Effect of Alkaline Treatment and Fibres Length on Mechanical Leaf Fibres Reinforced Polylactic Acid Biocomposites. *Jurnal Teknologi*, 79 (5-2), 5-2, 111-115.
2. S. H. S. Fadzullah, Z. Mustafa, **S. N. R. Ramli,** Q. A. Yaacob, A. Fatihah, and M. Yusoff, Preliminary Study on the Mechanical Properties of Continuous Long Pineapple Leaf Fibre Reinforced PLA Biocomposites, *Key Engineering Materials*, vol. 694, no. i, 2016, pp. 18–22.

PROCEEDING PAPER

1. **Ramli, S. N. R.,** Sheikh Md.Fadzullah, S. H., & Mustafa, Z. (2017). Low Velocity Impact Behaviour of Pineapple Leaf Fiber Reinforced Poly Lactic Acid Biocomposite. In *The 5th International Conference and Exhibition on Energy and Advanced Materials (ICE-SEAM2017)* (p. 53).
2. **S. N. R. Ramli,** S. H. S. Fadzullah, Z. Mustafa, *The effect of varying pressure on mechanical performance of pineapple leaf fibre reinforced poly lactic acid biocomposites*. Proceedings of Mechanical Engineering Research Day 2017, Melaka, 30 March 2017, pp. 131-132.
3. **S. N. R. Ramli,** S. H. S. Fadzullah, Z. Mustafa, *Mechanical performance of pineapple leaf fibre reinforced poly lactic acid (PLA) biocomposites*. Proceedings of Mechanical Engineering Research Day 2016, Melaka, 31 March 2016, pp. 131-132.
4. S. H. S. Fadzullah, Z. Mustafa, **S. N. R. Ramli,** *The effect of fibre length on the mechanical properties of pineapple leaf (PALF) fibre reinforced PLA biocomposites.* Proceedings of Mechanical Engineering Research Day 2016, Melaka, 31 March 2016, pp. 123-124.

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CHAPTER 1

INTRODUCTION

1.1 Background

This century has witnessed remarkable achievements in green technology in the field of biopolymer and bio-based materials. The primary goal of these developments is to save and protect the green atmosphere as contrasted to petroleum-derived materials. In addition, the high price of petroleum have also caused the bio-based materials to gain more attention (Herrera-Franco and Valadez-Gonzalez, 2005; Bledzki and Jaszkiewicz, 2010; Jamshidian et al., 2010; Pickering et al., 2011; Shalwan and Yousif, 2012 and Jia et al., 2014). Biofibres, biopolymers, biocomposites and allied biomaterials are potential alternative materials and products traditionally made from petroleum-based resources. To-date, there are many bio-based resources for new industrial applications, ranging from car components to consumer merchandises as well as packaging supplies to green construction products. The uses of fibre reinforced composites materials are becoming more versatile and famed due to the high strength-to-weight ratio together with easy manufacturing approaches (Holbery & Houston 2006; Hayes and Gammon, 2010; Faruk, et al. 2012 and Mohammad Asim et al., 2016).

Natural fibres such as hemp, flax, jute, kenaf, oil palm, and bamboo have drawn considerable attention in numerous industries such as automobiles, furniture, packaging and construction (Ochi, 2008). Their main interests in natural fibres over synthetic fibres are due to low cost, lightweight, carbon dioxide less-dependence on foreign oil resource and less damage to processing equipment. Other than that, natural fibres are plentifully

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